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Core stability and symmetry of youth female Volleyball players: a pilot study on anthropometric and physiological correlates

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Article

Core Stability and Symmetry of Youth Female Volleyball Players: A Pilot Study on Anthropometric and Physiological Correlates

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Abstract: The aim of the present study was to examine the variation in core stability and symmetry of youth female volleyball players by age, and its relationship with anthropometric characteristics, the 30 s Wingate anaerobic test (WAnT), and the 30 s Bosco test. Female volleyball players ($n = 24$, age 13.9 ± 1.9 years, mean \pm standard deviation) performed a series of anthropometric, core stability tests (isometric muscle endurance of torso flexors, extensors, and right and left lateral bridge), WAnT (peak power, mean power, Pmean, and fatigue index, FI) and Bosco test (Pmean). Flexors-to-extensors ratio and right-to-left lateral bridge ratio were also calculated. Participants were grouped into younger ($n = 12$, 12.3 ± 1.2 years) or older than 14 years ($n = 12$, 15.4 ± 1.0 years), and into normal (flexors-to-extensors ratio < 1 ; $n = 17$) or abnormal flexors-to-extensors ratio (≥ 1 ; $n = 7$). The older age group was heavier ($+11.3$ kg, mean difference; 95% CI, 2.0, 20.6) and with higher body mass index ($+2.8$ kg m⁻²; 95% CI, 0.4, 5.1) than the younger age group. The group with abnormal flexors/extensors had larger flexors muscle endurance ($+77.4$ s; 95% CI, 41.8, 113.0) and higher flexors/extensors ratio ($+0.85$; 95% CI, 0.61, 1.10) than the normal group. Body fat percentage (BF) correlated moderately-to-largely with flexors ($r = -0.44$, $p = 0.033$), extensors ($r = -0.51$, $p = 0.011$), and left lateral bridge ($r = -0.45$, $p = 0.027$); WAnT Pmean moderately-to-largely with right ($r = 0.46$, $p = 0.027$) and left lateral bridge ($r = 0.55$, $p = 0.006$); FI moderately-to-largely with right ($r = -0.45$, $p = 0.031$) and left lateral bridge ($r = -0.67$, $p < 0.001$), and right/left ratio ($r = 0.42$, $p = 0.046$); Bosco Pmean correlated moderately-to-largely with right ($r = 0.48$, $p = 0.020$) and left lateral bridge ($r = 0.67$, $p = 0.001$). A stepwise regression analysis indicated FI and BF as the most frequent predictors of core stability. The findings of the present study suggested that increased core stability was related to decreased BF and increased anaerobic capacity. A potential misbalance between torso flexors and extensors might be attributed to bidirectional variations (either high or low scores) of flexors muscle endurance rather than decreased extensors muscle endurance.

Keywords: human performance; muscle endurance; team sport; torso extensors; torso flexors

1. Introduction

Female volleyball has been one of the most popular team sports worldwide [1]. Performance in this sport has been associated with a series of physical, physiological, psychological and technique

and tactical characteristics [2,3]. With regards to physiological characteristics, most studies have focused on jumping ability and anaerobic power so far showing that female volleyball players jumped high and were characterized by high levels of anaerobic power [4,5]. Both jumping ability and anaerobic power might vary by age with adults scoring higher than adolescents [6]. Moreover, they might vary by in-game role of the players, e.g., higher jump height in hitters than libero players [6]. On the other hand, muscle endurance, i.e., the ability maintain muscle power output over time, in female volleyball—despite being a major component of health-related physical fitness—has received less scientific attention [7]. Muscle endurance has been considered not only in terms of absolute values, but also with regards to symmetry between different muscle groups (e.g., agonists versus antagonists) [7].

Core stability, i.e., the ability to optimize the placement and movement of the torso over the pelvis, has been recognized as a major component of muscle endurance. It was observed that core stability was beneficial for human performance, e.g., being stable reference would allow upper and lower limbs developing force [8], and health, e.g., maintenance of low back and knee health [9]. A low level of core stability increased the risk of low back and knee injuries [10]. In volleyball, those with core instability had high scapular malposition, inferior medial border prominence, coracoid pain, and dyskinesia of scapular movement [11]. Furthermore, the inclusion of core stability exercises was considered in preventive training programs [12,13]. With regards to the symmetry of the muscle endurance of torso muscles, e.g., flexors-to-extensors or right-to-left lateral flexors, few studies were conducted in sports [14,15] including volleyball [7]. It has been proposed that a ratio of torso flexors-to-extensors muscle endurance larger than one might indicate misbalance in the torso muscle groups [16], and consequently, this ratio could be used in volleyball to monitor muscle imbalances and identify potential injury risk. Volleyball included overhead tasks relied on shoulder movements, which in turn needed core stability to be efficient [7], and it has been shown that core stability might influence muscle strength of shoulders [17].

Although the abovementioned studies improved our understanding about the role of core stability and symmetry on health, little information existed about its role on performance in volleyball. The knowledge of the relationship of core stability and symmetry with anthropometric and physiological characteristics would be of practical value for professionals working with female volleyball players. In addition to the symmetry of core muscle endurance, it would be also interesting to examine the metabolic aspect, where it might be assumed that it would rely on the anaerobic energy transfer system considering its duration (several seconds) and exercise intensity (increased muscle activity) [18]. In exercise testing, the Wingate anaerobic test (WAnT) has been considered as a “golden” standard of anaerobic power and capacity despite its specific mode of exercise (cycling) [19]. A continuous 30 s Bosco jumping test has been developed as more sport-specific than WAnT to monitor performance, especially in sports involving many jumps [20,21]. Therefore, information on the relationship of core stability and symmetry with WAnT and Bosco test would provide insight into the metabolic demands of exercise testing of the former variables. In turn, anaerobic capacity has been shown to be inversely related with body fat percentage (BF) [22], i.e., the higher the BF, the lower the anaerobic capacity, and, consequently, it might be expected that BF would be related with core stability indices too.

With regards to correlates of core stability with physiological measures, research on female soccer players reported no correlation of core stability with sprint and muscle strength; however, this finding might be due to the sample size of this study [23]. In addition, information about the variation of core stability and symmetry by age in female volleyball would also be interesting in terms of training and testing. It has been shown that the prevalence of back pain was higher in 14–17 than 11–13 year-old athletes [24]. Moreover, anaerobic capacity assessed by the WAnT and Bosco test was larger in 14–18 than in under 14 year-old female volleyball players [25], whereas no difference was observed in sit-ups test between under and over 14 years female volleyball players [26]. However, no information on age related differences in volleyball has been examined previously with regard to core stability and symmetry. Therefore, the aim of the present study was to examine the variation in core

stability and symmetry of female volleyball players by age and its relationship with anthropometric characteristics, WAnT, and the Bosco test. A secondary aim was to compare examine differences between groups varying for torso flexors-to-extensors ratio as it was suggested that a ratio ≥ 1 would indicate misbalance [16]. The research hypothesis was that increased core stability indices would be associated with high scores of WAnT and Bosco test indices, and low BF. Since anaerobic capacity and body composition were related to performance [4,5], a potential association of core stability indices with these variables would highlight the relevance of core stability with performance.

2. Materials and Methods

2.1. Study Design and Participants

Female volleyball players ($n = 24$, age 13.9 ± 1.9 years) performed a series of anthropometric, core stability (isometric muscle endurance of torso flexors, extensors, and right and left lateral bridge) and WAnT (peak power, mean power, P_{mean} , and fatigue index, FI, were estimated). Since there was no information about minimal level of effect size in the differences between groups that would be of scientific interest, the sample size was selected considering previous studies [7,23]. Flexors-to-extensors ratio and right-to-left lateral bridge ratio were also calculated to evaluate the symmetry of the core stability variables. Participants were volleyball players of a sport club in Athens and volunteered for this study. They had sport experience 2.9 ± 1.9 years, practiced volleyball 3.7 ± 1.0 days per week with each training session lasting 93 ± 10 min, a total weekly training volume 348 ± 124 min and participated in one official game per week. After being informed with details about all procedures, participants and their guardians provided their consent to participate. The exercise testing was performed in a single session. The study was approved by the local Committee of Ethics (EPL 2019/12). Participants were grouped into younger ($n = 12$, age 12.3 ± 1.2 years, sport experience 2.5 ± 1.6 years, 3.6 ± 0.6 weekly training units, and volume 321 ± 54 min) or older than 14 years ($n = 12$, 15.4 ± 1.0 years, 3.4 ± 2.1 years, 3.8 ± 1.2 and 374 ± 166 min, respectively), and into normal (flexors-to-extensors ratio < 1 ; $n = 17$) or abnormal flexors-to-extensors ratio (≥ 1 ; $n = 7$) according to the classification of McGill [16]. An age of 14 years has been suggested to categorize pubertal status in girls [27] and classified adolescent female volleyball players into age groups [25,26]. Considering the sample size and their small sport experience, the participants were not grouped by playing position.

2.2. Equipment and Procedures

Participants were evaluated for stature (SECA, Leicester, UK) and body mass (HD-351 Tanita, City, IL, USA) to the nearest 0.1 cm and 0.1 kg, respectively. The thickness of ten skinfolds (cheek, chin, pectoral, triceps, subscapular, abdomen, chest II, iliac crest, patella and proximal calf) was measured on the right side of the body to the nearest 0.1 mm (Harpenden, West Sussex, UK) and was used to estimate BF according to a Parizkova equation described by Eston and Reilly [28]. After a standardized warm-up including 9 min submaximal cycling and 6 min stretching exercises, participants performed the 30 s Wingate anaerobic test (WAnT) on a cycle ergometer (874 Ergomedic, Monark, City, Sweden) against braking force $0.075 \times$ body mass providing peak power (P_{peak} , W kg^{-1}), mean power (P_{mean} , W kg^{-1}), and fatigue index (FI, %). Participants were informed that WAnT was an all-out test not allowing the adoption of a pacing strategy, and were encouraged continuously during the test to exert maximal effort. In addition, a continuous 30 s jumping Bosco test was performed, where the participants were instructed to jump continuously throughout this period aiming to achieve maximal jump height in each jump, minimal time spent at the ground between consecutive jumps and maintaining their hands on the hips [20]. The mean power (P_{peak} , W kg^{-1}) was the outcome measure of the Bosco test.

To assess core stability, four primary (torso flexors, extensors, right and left lateral bridge test) and two secondary measures (flexors to extensors ratio and right to left lateral ratio) following the recommendations of Hoogenboom and Bennett [29] were performed. Participants were familiarized with these measures, since they were included in their training routine. In the torso flexors test,

the participant adopted a sit-up position at angle 60° from the floor, whereas, in the torso extensors test, the participant was with her upper body unsupported out of a table and an ankle 180° at hips. In the lateral bridge test, the participant was lying using a side-bridge position. A few seconds practice was provided prior to testing to explain the correct position. A single trial was performed for each test and a 5-min break was provided between tests to allow sufficient recovery [18]. In each test of core stability, participants were asked to maintain the correct position as much as possible. Each primary measure was evaluated in the nearest 0.1 s; thereafter, the secondary measures were calculated to the nearest 0.1. The timing of each test started when participants adopted the instructed position and stopped when a deviation from the position was observed. This protocol evaluated core stability and symmetry previously in female and male soccer players [14,15]. Reliability coefficients ranged from 0.93 (flexors), and 0.96 (right later bridge) to 0.99 (extensors and left lateral bridge) [18].

2.3. Statistical and Data Analyses

IBM SPSS v.23.0 (SPSS, Chicago, USA) and Graphpad v.7.0 (GraphPad Prism, San Francisco, CA, USA) were used for statistical analyses. Although the data did not present normal distribution according to visual inspection of Q–Q plots and Shapiro–Wilk test (since n was lower than 50), parametric statistics were used to provide comparable methods and analysis with previous studies on core stability [16,18,23,29]. A non-parametric statistics (median, inter-quartile range, Mann–Whitney U test for differences between groups and Spearman rho for correlations among variables) were also presented in Tables 1–3 to maintain the statistical integrity of this paper. Data were expressed as mean and standard deviation. A preliminary examination of potential relationship of training characteristics with the variables of interest did not reveal any significant correlation; thus, training characteristics were not considered as covariate. An independent student t -test examined differences between age groups (under 14 years versus over 14 years) and torso flexors-to-extensors ratio groups (normal versus abnormal). The magnitude of these differences was evaluated by Cohen's d , classified as trivial ($d \leq 0.2$), small ($0.2 < d \leq 0.6$), moderate ($0.6 < d \leq 1.2$), large ($1.2 < d \leq 2.0$), or very large ($d > 2.0$) [30]. The relationship of core stability and symmetry (torso flexors, extensors, right and left lateral bridge test, flexors to extensors ratio, and right to left lateral ratio) with anthropometric characteristics (age, height, weight, body mass index and BF), WAnT (Ppeak, Pmean and FI), and Bosco test (Pmean) was examined using Pearson correlation r . A step-wise regression analysis examined predictors of core stability and symmetry. Statistical significance was set at alpha 0.05.

Table 1. Descriptive statistics by age group.

Variable	Under 14 Years ($n = 12$)		Over 14 Years ($n = 12$)	
	Mean \pm SD	Median (IQR)	Mean \pm SD	Median (IQR)
Anthropometry				
Age (years)	12.3 \pm 1.2	12.5 (11.1–13.4)	15.4 \pm 1.0 **	15.5 (14.6–15.9) **
Body mass (kg)	53.3 \pm 8.5	54.7 (44.7–60.8)	64.6 \pm 12.9 *	62.4 (53.6–75.4)
Height (m)	1.60 \pm 0.08	1.60 (1.53–1.66)	1.66 \pm 0.07	1.68 (1.60–1.72)
BMI (kg.m ⁻²)	20.6 \pm 2.3	20.8 (18.1–22.5)	23.4 \pm 3.1 *	22.8 (20.4–25.8) *
BF (%)	23.8 \pm 5.4	23.8 (20.1–28.7)	25.0 \pm 3.5	25.3 (23.2–27.7)
Core stability				
Flexors (s)	86.8 \pm 69.6	55.5 (33.8–138.9)	66.8 \pm 23.8	64.9 (46.5–80.0)
Extensors (s)	107.6 \pm 50.0	96.2 (71.7–138.9)	109.6 \pm 25.1	107.4 (92.3–122.6)
Right lateral (s)	31.3 \pm 17.5	34.6 (11.5–48.9)	35.0 \pm 13.3	35.6 (20.9–45.4)
Left lateral (s)	34.8 \pm 16.3	35.1 (22.4–51.0)	42.7 \pm 16.8	44.4 (33.6–48.0)
Flexors/extensors	0.84 \pm 0.60	0.65 (0.31–1.22)	0.64 \pm 0.28	0.52 (0.43–0.79)
Right/left lateral	0.90 \pm 0.28	0.89 (0.77–1.08)	0.92 \pm 0.41	0.85 (0.61–1.16)

Table 1. Cont.

Variable	Under 14 Years (<i>n</i> = 12)		Over 14 Years (<i>n</i> = 12)	
	Mean \pm SD	Median (IQR)	Mean \pm SD	Median (IQR)
WAnT				
Ppeak (W kg ⁻¹)	8.28 \pm 0.81	8.35 (7.69–8.84)	8.85 \pm 0.47	8.86 (8.72–9.13) *
Pmean (W kg ⁻¹)	5.94 \pm 0.78	5.99 (5.13–6.59)	6.57 \pm 0.84	6.74 (6.00–6.86)
FI (%)	49.9 \pm 8.0	50.7 (42.6–55.0)	45.9 \pm 7.1	45.5 (41.3–46.6)
Bosco test				
Pmean (W kg ⁻¹)	24.1 \pm 4.1	23.7 (20.8–26.4)	25.4 \pm 4.1	24.8 (23.1–26.5)

SD = standard deviation, IQR = inter-quartile range, BMI = body mass index, BF = body fat percentage, flexors-to-extensors ratio, right-to-left lateral bridge ratio, WAnT = Wingate anaerobic test, Ppeak = peak power, Pmean = mean power, FI = fatigue index; * $p < 0.05$, ** $p < 0.001$.

Table 2. Descriptive statistics by flexors-to-extensors ratio group.

Variable	Normal Flexors-to-Extensors (<i>n</i> = 17)		Abnormal Flexors-to-Extensors (<i>n</i> = 7)	
	Mean \pm SD	Median (IQR)	Mean \pm SD	Median (IQR)
Anthropometry				
Age (years)	13.9 \pm 2.1	14.1 (11.9–15.6)	13.7 \pm 1.3	13.7 (13.0–14.6)
Body mass (kg)	60.1 \pm 13.3	56.1 (53.3–71.4)	56.2 \pm 9.0	60.1 (44.8–62.2)
Height (m)	1.63 \pm 0.08	1.64 (1.57–1.70)	1.63 \pm 0.09	1.65 (1.53–1.67)
BMI (kg.m ⁻²)	22.4 \pm 3.3	22.4 (19.8–24.9)	21.0 \pm 2.1	22.1 (19.0–22.5)
BF (%)	25.2 \pm 4.7	25.7 (23.4–28.9)	22.3 \pm 3.2	22.6 (20.0–24.5)
Core stability				
Flexors (s)	54.2 \pm 20.6	53.8 (41.0–72.9)	131.6 \pm 65.0 *	123.9 (68.2–193.2) **
Extensors (s)	114.1 \pm 39.8	107.9 (84.4–133.3)	95.2 \pm 35.0	102.1 (62.2–107.7)
Right lateral (s)	32.9 \pm 14.3	30.4 (18.2–44.9)	33.8 \pm 18.8	39.9 (9.0–50.6)
Left lateral (s)	36.8 \pm 13.8	38.8 (29.4–48.8)	43.5 \pm 23.0	39.5 (32.5–56.6)
Flexors/extensors	0.49 \pm 0.18	0.46 (0.36–0.65)	1.35 \pm 0.40 *	1.17 (1.10–1.64) *
Right/left bridge	0.95 \pm 0.36	0.89 (0.73–1.20)	0.82 \pm 0.30	0.89 (0.65–1.10)
WAnT				
Ppeak (W kg ⁻¹)	8.55 \pm 0.69	8.78 (8.31–8.94)	8.59 \pm 0.82	8.81 (7.56–9.17)
Pmean (W kg ⁻¹)	6.13 \pm 0.89	6.46 (5.22–6.80)	6.61 \pm 0.72	6.55 (5.99–6.99)
FI (%)	48.7 \pm 7.9	46.4 (44.3–53.4)	45.8 \pm 7.1	44.9 (40.4–55.0)
Bosco test				
Pmean (W kg ⁻¹)	24.1 \pm 4.2	24.3 (20.2–26.4)	26.1 \pm 3.7	25.4 (23.6–26.5)

IQR = inter-quartile range, BMI = body mass index, BF = body fat percentage, flexors-to-extensors ratio, right-to-left lateral bridge ratio, WAnT = Wingate anaerobic test, Ppeak = peak power, Pmean = mean power, FI = fatigue index; * $p < 0.001$, ** $p < 0.01$.

Table 3. Correlations r (Spearman rho in brackets) of core stability and symmetry indices with anthropometric characteristics and Wingate anaerobic test.

Variable	Core Stability and Symmetry					
	Flexors (s)	Extensors (s)	Right Lateral (s)	Left Lateral (s)	Flexors/Extensors	Right/Left
Age (years)	−0.06 (0.06)	−0.21 (−0.05)	−0.05 (−0.06)	0.12 (0.12)	0.06 (0.10)	−0.11 (−0.13)
Body mass (kg)	−0.23 (−0.13)	−0.32 (−0.29)	−0.27 (−0.31)	−0.21 (−0.17)	−0.11 (0.03)	0.18 (−0.10)
Height (m)	−0.06 (0.04)	−0.26 (−0.12)	−0.19 (−0.20)	−0.04 (−0.05)	<0.01 (0.14)	−0.02 (−0.10)
BMI (kg m ⁻²)	−0.31 (−0.18)	−0.35 (−0.34)	−0.30 (−0.27)	−0.30 (−0.23)	−0.16 (−0.02)	0.24 (0.04)
BF (%)	−0.44 * (−0.46 *)	−0.51 * (−0.26)	−0.36 (−0.34)	−0.45 * (−0.53 **)	−0.27 (−0.33)	0.18 (0.16)
Ppeak (W kg ⁻¹)	−0.20 (0.03)	−0.10 (−0.14)	−0.01 (−0.11)	0.04 (−0.06)	−0.09 (0.10)	−0.01 (−0.18)

Table 3. Cont.

Variable	Core Stability and Symmetry					
	Flexors (s)	Extensors (s)	Right Lateral (s)	Left Lateral (s)	Flexors/Extensors	Right/Left
WAnT Pmean (W kg ⁻¹)	0.29 (0.49 *)	0.19 (0.12)	0.46 * (0.39)	0.55 ** (0.53 *)	0.30 (0.39)	−0.13 (−0.18)
FI (%)	−0.39 (−0.54 **)	−0.14 (−0.07)	−0.45 * (−0.41)	−0.67 *** (−0.66 **)	−0.39 (−0.41)	0.42 * (0.33)
Bosco Pmean (W kg ⁻¹)	0.25 (0.45 *)	0.24 (0.16)	0.48 * (0.50 *)	0.67 ** (0.63 **)	0.19 (0.32)	−0.20 (−0.07)

BMI = body mass index, BF = body fat percentage, flexors-to-extensors ratio, right-to-left lateral bridge ratio, Ppeak = peak power, WAnT = Wingate anaerobic test, Pmean = mean power, FI = fatigue index; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3. Results

The older age group differed in age from the younger one by 3.1 years (95% confidence intervals, CI, 2.2, 4.0; Cohen's $d = 2.8$), was heavier (+11.3 kg, mean difference; 95% CI, 2.0, 20.6; $d = 1.0$) and had a higher body mass index (+2.8 kg m⁻²; 95% CI, 0.4, 5.1; $d = 1.0$) (Table 1). No other difference was observed between age groups ($p > 0.05$). The group with abnormal flexors/extensors had larger flexors muscle endurance (+77.4 s; 95% CI, 41.8, 113.0; $d = 1.6$) and lower flexors/extensors (+0.85; 95% CI, 0.61, 1.10; $d = 2.8$) than the normal group (Table 2). No other difference was shown between flexors/extensors groups ($p > 0.05$).

The correlations of core stability and symmetry indices with anthropometric characteristics, WAnT and Bosco test were presented in Table 3. BF correlated moderately-to-largely with flexors, extensors and left lateral bridge, WAnT and Bosco Pmean moderately-to-largely with right and left lateral bridge, and FI moderately-to-largely with right and left lateral bridge, and right/left ratio. Representative correlations were depicted in Figure 1. The findings of the stepwise regression analysis were presented in Table 4. FI and BF were the most frequent predictors of core stability and symmetry.

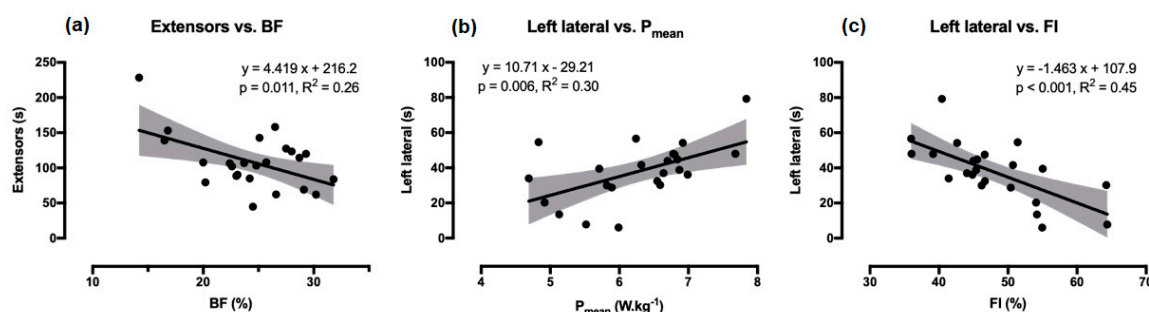


Figure 1. Relationship of core stability with body fat percentage (BF; a), mean power (Pmean; b), and fatigue index (FI; c) of the Wingate anaerobic test.

Table 4. Stepwise regression analysis.

Variable	Core Stability and Symmetry					
	Flexors (s)	Extensors (s)	Right Lateral (s)	Left Lateral (s)	Flexors/Extensors	Right/Left
Predictors	BF, FI	BF	WAnT Pmean, Ppeak	FI, Bosco Pmean	BF, FI	FI
R	0.75	0.51	0.73	0.85	0.71	0.42
R2	0.56	0.26	0.54	0.72	0.50	0.18
SEE	37.9	34.0	11.1	9.3	0.35	0.33

BF = body fat percentage, flexors-to-extensors ratio, right-to-left lateral bridge ratio, Ppeak = peak power, Pmean = mean power, FI = fatigue index, WAnT = Wingate anaerobic test; SEE = standard error of the estimate.

4. Discussion

The main findings of the present study were that (a) no difference in core stability and symmetry was observed between age groups; (b) participants with abnormal flexors-to-extensors ratio had more

muscle endurance in flexors than those with normal ratio; (c) flexors and extensors muscle endurance correlated with BF, i.e., the larger the muscle endurance, the lower the BF; (d) lateral muscle endurance correlated with indices of WAnT and Bosco test; and (e) FI and BF were the most frequent predictor of core stability and symmetry.

Considering the role of age, the comparison between age groups (~12 versus ~15 years) did not show any difference in core stability and symmetry, which was in agreement with a study on adolescent non-athletes [31]. It might be assumed that the intermittent nature of volleyball did not facilitate the development of muscle endurance. The relationship of core stability with BF might be attributed to the negative role of BF in exercise performance related to muscle endurance and anaerobic capacity [22,32]. Previously, it was observed that BF correlated with WAnT Pmean in both adolescent and adult female volleyball players [22], where high BF was related to low WAnT Pmean. It has been also shown that a higher BF was related to a lower number of sit-ups in 1 min in female police officers [32]. This negative role of BF for core stability and muscle endurance might be that fat was an extra load that should be sustained without contributing to muscle contraction.

Core stability indices (lateral bridge) correlated either with WAnT Pmean, i.e., mean cycling performance over 30s, or FI, i.e., percentage decrease of cycling performance over 30 s. Particularly, a high score of lateral bridge was related to high score of Pmean and low score of FI. It should be highlighted that a low score of FI in WAnT-combined with adequate Pmean-indicated high anaerobic capacity, since a participant was able to maintain performance during prolonged exercise [33]. On the other hand, no correlation was observed between core stability and Ppeak, i.e., performance in the first 5 s of WAnT. This finding was in agreement with a study in female and male soccer players, where core stability did not correlate with isometric muscle strength [15]. From a physiological point of view, core stability tests lasting from 6 s to 230 s had closer affinity with anaerobic capacity (WAnT Pmean and FI) rather than muscle power (Ppeak) and muscle strength. Moreover, it has been observed that exercise duration might partially explain the similar results of two different modes (cycling versus jumping) of exercise tests [21]. With regard to the correlations of the Bosco test, it was observed that the performance on this test correlated moderately-to-largely with torso lateral flexors muscle endurance. This observation was in agreement with research showing that torso lateral flexors had substantial potentials as stabilizers and energy generators during jumps [34] and played an important role in single-leg jumps independently of vertical or horizontal direction [35].

With regard to torso flexors-to-extensors ratio, it was found that an increased ratio in the abnormal group was due to an increased score of flexors. A ratio of 1.15 was observed in workers with a history of back disorders compared to 0.71 in their healthy counterparts [16], where the 1.15 ratio was attributed more to weak extensors rather than to strong flexors. These findings implied that, although the abnormal group of volleyball players had increased flexors-to-extensors ratio—observed also in a group with history of back disorders [16]—a different aetiology might be assumed (increased muscle endurance of flexors in the former group versus decreased muscle endurance of torso extensors in the latter group). The overall torso flexors-to-extensors ratio in the present study (0.74) was similar to that of healthy adults (0.71) [16] and adult female volleyball players (0.73) [7]. It should be highlighted that, although our results about torso flexors-to-extensors ratio were similar to their adult counterparts [7], the absolute scores of torso flexors and extensors muscle endurance were quite lower in our sample. Thus, the higher values of torso flexors and extensors in adult female volleyball players [7] might be attributed to a long-term training effect. Moreover, low back pain was associated with torso extensors and flexors weakness [36]. With regard to the normal group, i.e., the group with torso flexors-to-extensors ratio lower than one, it was observed that this ratio (0.49) was lower than that reported by literature on healthy adults and adult female volleyball players (~0.72) [7,16]. It was also shown that this decreased ratio was attributed more to decreased flexors muscle endurance rather than to the score of extensors. Thus, a training aim should be to prevent torso flexor-to-extensors misbalance in both directions (i.e., low or high scores of flexors muscle endurance).

The mean score of right-to-left lateral bridge (≥ 0.90) indicated a relative symmetry between right and left side of the torso; however, the large variation of scores of the right-to-left lateral bridge ratio shown by SD 0.28–0.41 suggested a lack of symmetry between the two sides, i.e., there were participants with large differences in muscle endurance between right and left torso flexors. On the other hand, SD as a measure of inter-individual variation should be interpreted with caution considering the lack of normal distribution of the data as indicated by non-parametric statistics (Tables 1 and 2). These findings highlighted the need for a balanced training load between torso flexors and extensors as well as between right and left lateral muscle groups.

A limitation of the present study was that the exercise tests of core stability relied on isometric muscle contraction; thus, caution would be needed to generalize the findings to exercise tests using other modes of muscle contraction (isotonic or isokinetic). Furthermore, special attention would be necessary when performing exercise tests of core stability such as torso flexors, since even a minimal deviation from the correct position would result in altered muscle activation influencing the outcome [37]. It was also acknowledged that other assessment methods of muscle symmetry (e.g., surface electromyography and isokinetic dynamometry) should be selected in future studies to verify our findings by using laboratory methods. On the other hand, the strength of this study was its novelty as it provided evidence about the relationship of core stability indices with BF, WAnT, and the Bosco test. In addition, the findings had practical applications for physicians, exercise physiologists, and fitness trainers to monitor the training of volleyball players. Performance in volleyball relied on the effectiveness of the dynamic movements of the shoulder, which in turn performed movements taking advantage of a stable torso; in this sense, although the core did not participate directly in dynamic movements, its optimal muscle function was necessary to stabilize the shoulder zone and pelvis in order for upper and lower limbs to perform efficiently [7]. Since data on core stability of adolescent female volleyball players were not available in the existed literature, practitioners might use our findings as reference to evaluate core stability and symmetry of their athletes. Although a correlation would not indicate causation, the knowledge of the relationship of core stability with BF, WAnT, and the Bosco test would aid practitioners in the interpretation of core stability measurements, e.g., a low score of core stability of an athlete with high BF might be attributed to an excess BF in addition to a likely muscle weakness.

5. Conclusions

The findings of the present study suggested that increased core stability was related to decreased BF and increased anaerobic capacity. A potential misbalance between torso flexors and extensors might be attributed to bidirectional variations (either high or low scores) of flexors rather than decreased extensors muscle endurance. Considering the lack of available data on core stability and symmetry in adolescent female volleyball players, our findings could be used by practitioners in the context of testing and training.

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